Enhancing Long Range Sonar Performance in Range-Dependent Fluctuating Ocean Waveguides by Mitigating Biological Clutter and Environmental Reverberation

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LONG-TERM GOALS AND OBJECTIVES

Determine the temporal and spatial characteristics, and physical mechanisms for clutter and environmental reverberation in long range underwater acoustic imaging and surveillance systems. This understanding is used to develop operational and signal processing techniques to distinguish clutter from scattered returns due to man-man targets, and to determine the limits placed by environmental reverberation on target detection. In the second area, the statistical properties of broadband acoustic signals transmitted and scattered in range-dependent ocean waveguides are examined. This knowledge is then used to determine the extent to which environmental variabilities limit our ability to perform target localization and parameter estimation through beamforming and matched-filtering broadband data for imaging systems in fluctuating and dispersive ocean waveguides.

APPROACH

The research effort involves developing and enhancing physics-based theoretical models for scattering from groups of fish, marine mammals and other biological organisms, multi-static scattering from extended targets, and environmental reverberation in *range-dependent* ocean waveguides. The data from the ONR-sponsored experiments in the Gulf of Maine in 2006 and on the New Jersey Strataform in 2003 measured with wide-area ocean acoustic waveguide remote sensing systems are processed and analyzed.

WORK COMPLETED AND RESULTS

1. Probability Distribution for Energy of Saturated Broadband Ocean Acoustic Transmission: Results from Gulf of Maine 2006 Experiment

The probability distribution for saturated broadband ocean-acoustic signal energy has been derived using coherence theory as a function of the signal bandwidth, measurement time, frequency and temporal correlation of its energy spectral density. The derivation assumes the broadband signal is composed of frequency components from Fourier analysis that are each fully saturated with energy spectral density that obey the exponential distribution with 5.6 dB standard deviation and unity scintillation index. When the signal bandwidth and measurement time are larger than the correlation bandwidth and correlation time of its energy spectral density components respectively, the broadband

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signal energy obtained by integrating the energy spectral density across the signal bandwidth then follows the Gamma distribution. The broadband signal energy has a standard deviation that can be significantly smaller than 5.6 dB and a scintillation index less than unity. This is because forward propagation and scattering through the random ocean environment causes the broadband signal to decorrelate across its bandwidth or over time. The theory is verified with broadband transmissions in the Gulf of Maine shallow water waveguide in the 300-1200 Hz frequency range. The transmissions were found to be saturated, where the exponential distribution and standard deviation near 5.6 dB were observed for the energy spectral density components of the measured signals. The bandwidth-integrated signal energies matched well with the Gamma distribution with standard deviations ranging from 2.7 to 4.6 dB for effective bandwidths up to 42 Hz. The measured standard deviations and scintillation indices were found to be smaller for signals with lower center frequencies and larger bandwidths. The energy spectral density correlation bandwidths of the broadband signals were found to be larger for signals with higher center frequencies, and can be approximated as roughly 10% of the center frequency.

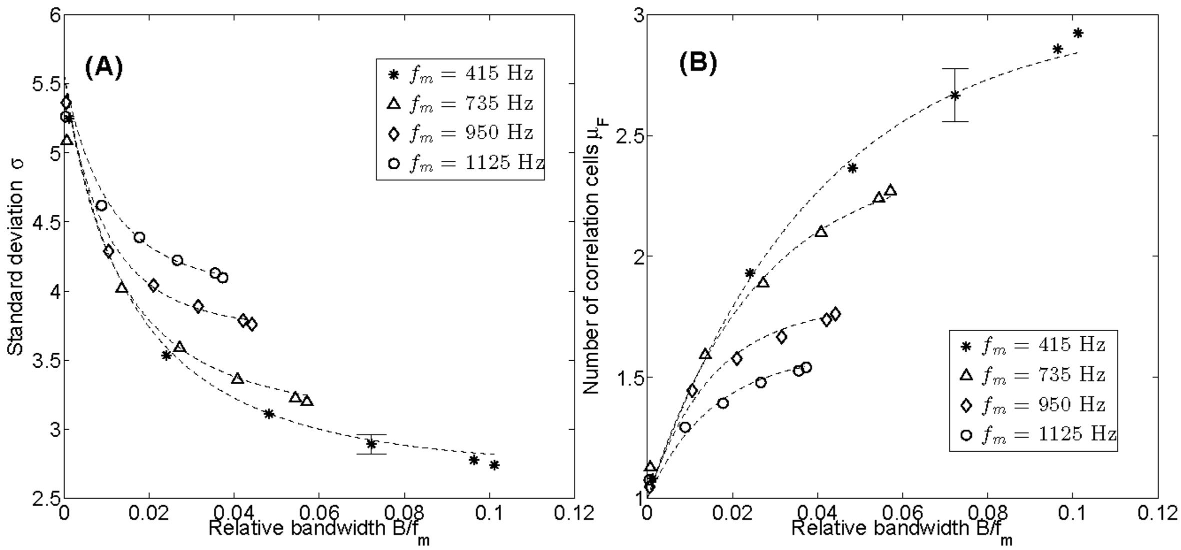

Figure 1: (A) Empirically measured standard deviations of the log-transformed bandwidth averaged energy spectral densities obtained from broadband transmissions in the Gulf of Maine shown as points. (B) The number of frequency correlation cells μ_F are obtained from the measured signal standard deviations. The errorbar shown applies to all data points. Figure taken from Ref. 1.

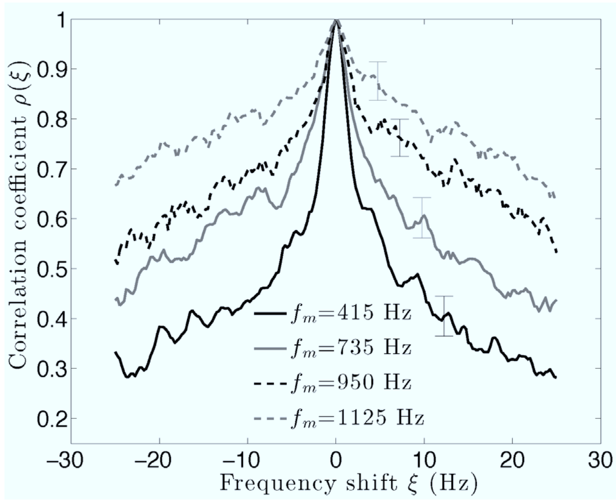

Figure 2: Average energy spectral density correlation coefficient calculated from received broadband signals in the Gulf of Maine at the four center frequencies shown as a function of frequency shift within the signal bandwidth. This figure shows that the lower center frequency signals are less strongly correlated over the signal bandwidth than the high center frequency signals.

2. *Instantaneous Wide-Area Passive Source Localization and Tracking Approaches with A Single High-Resolution Towed Horizontal Receiver Array*

Approaches for instantaneous passive localization and tracking of acoustic sources over long ranges with measurements made on a single high-resolution towed horizontal receiver array in a random range-dependent ocean waveguide are examined. Towed horizontal receiver arrays are employed in a wide range of applications in the ocean, such as naval operations for detecting and tracking underwater vehicles; active and/or passive sensing of marine life, oceanography, and ocean geology; and for oil and natural gas exploration. An advantage of sensing with a horizontal array of hydrophones is that the bearing of the sound source can be directly obtained by beamforming the received signals so that only the range of the source to the receiver has to be determined.

Four distinct methods that can provide instantaneous or near-instantaneous estimates of source range in the far-field of a single high-resolution towed horizontal receiver array are examined. They include (1) synthetic aperture tracking (SAT), which combines measurements made on adjacent or widely separated finite apertures of a single towed receiver array and employs the conventional triangulation ranging algorithm for localizing sources located in the far-field of the receiver array; (2) array invariant (AI), a technique that exploits the dispersive modal arrival structure of the acoustic field in an ocean waveguide to estimate the source range for sources located off the broadside beam of the receiver array; (3) the bearings-only target motion analysis in modified polar coordinates implemented using the extended Kalman filter (MPC-EKF) where the bearing and range components of the source location and velocity state vector are decoupled, and (4) bearings-migration minimum mean square error (MMSE), which is also based on triangulation but combines sequential bearing measurements in a global inversion for the mean source position over the measurement time interval. These methods are applied to localize and track a vertical source array deployed in the far-field of a towed horizontal receiver array during the Gulf of Maine 2006 Experiment. The source transmitted intermittent

broadband pulses in the 300-1200 Hz frequency range. The performance of all four methods are evaluated for a wide variety of source-receiver geometries and range separations up to 20 km. The source localization accuracy is found to be highly dependent on source-receiver geometry and the localization approach. For a relatively stationary source drifting at speeds much smaller than the receiver array tow speed, the mean source position can be estimated by synthetic aperture tracking with less than 3% error near broadside direction. For a moving source, the Kalman filter method gave the best performance with 5.5% error. The array invariant is the best approach for localizing sources within the endfire beam of the receiver array with roughly 7% error.

IMPACT/APPLICATIONS

We showed that broadband acoustic signals in shallow water undergo less fluctuations than monochromatic signals so that fewer measurements or smaller sample sizes are necessary to achieve desired accuracy in broadband active/passive sensing or communication applications.

RECENT PUBLICATIONS

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